Chapter 1

Physics Requirements

1.1 Energy Asymmetry

The required energy asymmetry at KEKB is derived from considerations on the physics program. The major part of the research topic is a study on CP violation in decays of neutral B mesons, where decay modes such as $B \to J/\psi K_S$ need to be reconstructed. The magnitude of CP violation is expected to be $O(10\%)$ according to the Standard Model. For this study, B mesons with finite momenta have to be produced so that the time evolution of their decay pattern can be measured. The B mesons produced in decays of Υ(4s) at rest do not suit this purpose, because in this condition the B mesons will have only a small fixed momentum of 300 MeV in the laboratory frame. An e^+e^- collider with an asymmetric energy collision is required to produce Υ(4s)s which are moving along the beam axis in the laboratory frame.

The energy asymmetry is characterized by the motion of the center of mass of the $B\bar{B}$ system in the laboratory frame. Its Lorentz boost parameter is written as

$$\beta\gamma = \frac{E_- - E_+}{\sqrt{s}}. \tag{1.1}$$

Here, the E_- and E_+ are the energies of the electron and positron beams, respectively. The $\sqrt{s}$ is the center-of-mass energy, which can be written as $\sqrt{s} = \sqrt{4E_-E_+}$. It is equal to the rest mass of Υ(4s), 10.58 GeV.

With a larger energy asymmetry, time evolution measurements can be done with better accuracy. However, the effective acceptance of the detector with a fixed geometry will be reduced. The optimum value of the asymmetry must be found by taking into account these two factors. Figure 1.1 shows the total integrated luminosity that is required to observe CP violation as a 3 standard deviation signal as a function of $\beta\gamma$.

It is seen that the asymmetry values between $\beta\gamma$=0.4 and 0.8 result in a similar sensitivity for this measurement.

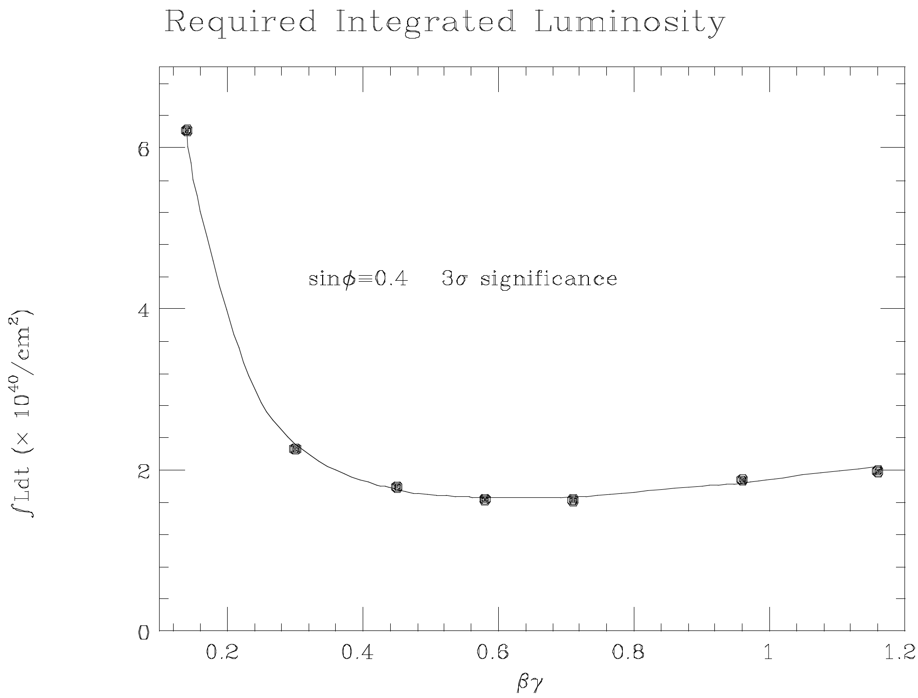

Figure 1.1: Required integrated luminosity for observing CP violation, as a function of energy asymmetry ($\beta\gamma$).

On the other hand, it should be pointed out that there are a number of other physics topics involving B meson decays, where studies of the decay time evolution are not required. For these processes, a smaller asymmetry is preferred for a larger acceptance and for a better event reconstruction efficiency [1].

Combining these considerations, the energy asymmetry has been chosen as $\beta\gamma$=0.42, which is obtained by

$$E_- = 8.00\ GeV \tag{1.2}$$

$$E_+ = 3.50\ GeV \tag{1.3}$$

1.2 Luminosity

For measuring the CP violation in the decay $B \to J/\psi K_S$, the required integrated luminosity is estimated to be between 30 and 100 fb^{-1}. The uncertainty of this estimate arises from quoted errors in the experimental data and their theoretical interpretations.

Other channels to measure CP violation have been also studied. It is estimated that at least 100 fb^{-1} of the integrated luminosity is necessary to measure other important parameters in the Standard Model.

The CLEO-II experiment at CESR is presently collecting data with a world-record high luminosity of a few $\times 10^{32}$ cm^{-2}s^{-1}. They are expected to collect 20 fb^{-1} by the time KEKB starts data taking. Studies on a variety of rare decay modes of B mesons will have been conducted by then. A desire to go beyond the statistical sensitivity available at CLEO-II adds another reason why KEKB should collect more than 100 fb^{-1}.

From these considerations, it is concluded that the target luminosity for the first few years of the experiment should be 100 fb^{-1}. To achieve this in a timely manner, the target peak luminosity for KEKB should be 1.0×10^{34} cm^{-2}s^{-1}.

1.3 Energy Range

Three Υ resonances are known to exist below the $B\bar{B}$ threshold, while the first resonance above the $B\bar{B}$ threshold is Υ(4s) at 10.58 GeV. The Υ(4s) decays almost exclusively into $B\bar{B}$ (either B_u or B_d), and it is at this resonance that the bulk of data should be collected at KEKB.

However, some data need to be collected at different center-of-mass energies for the following reasons.

- An energy scan is required to find the peak of $\Upsilon(4s)$. This is to ensure that the data taking is conducted at the most efficient energy. Since the mass and width of Υ(4s) is well known from measurements by CLEO, it also serves the purpose of cross-calibration of the machine configuration at KEKB. The width of the energy scan can be as small as 30 MeV, and the number of the data points will be at most 10.

- Off-resonance data have to be collected to understand $q\bar{q}$ continuum events. This is important for some data analyses where the continuum background has to be statistically subtracted. An integrated luminosity of more than 10% of the on-resonance data will be required for this purpose. The energy of the off-resonance run should be 10.50 GeV, where the cross section of the $B\bar{B}$ pair-production is negligibly small. At KEKB this determines the lowest center of mass energy for the required run.

- It has been pointed out that studies of B_s should provide additional information on b-quark decays. For this purpose it is necessary to go to Υ(5s) (10.87 GeV) to produce B_s mesons. However, its production rate is expected to be $O(\frac{1}{10})$ of the $B_{u,d}$ production rate at Υ(4s). The present perspective is that the measurement of B_s will be done only after a significant amount of data is collected for $B_{u,d}$ at

Υ(4s). At KEKB this specifies the highest center of mass energy for the required run.

It is concluded that the energy coverage by KEKB should be between 10.4 and 11.0 GeV, which includes a small margin on the higher and lower ends.

$$\sqrt{4E_{-}E_{+}} = 10.4 \sim 11.0 \; GeV \tag{1.4}$$

Throughout these runs, the energy asymmetry should be kept at $\beta\gamma$=0.42.

1.4 Beam Energy Spread

In the experiment at KEKB, rare decays of B mesons need to be reconstructed, where the combinatorial background from continuum events can be significant. In many of those decay modes, a reduction of this background is equivalent to an increase of the effective luminosity from the viewpoint of statistical significance.

It has been shown by simulation studies that the signal-to-noise ratio S/N of the B decay reconstruction is approximately inversely proportional to the beam energy spread [2]. By applying an adequate Lorentz boost according to the beam energy, the measured momentum vectors of B meson decay products can be brought into the rest frame of Υ(4). The momentum of the B in this frame will have a fixed value of 300 MeV. This can be used as a powerful constraint for finding B. The effectiveness of this technique depends on the magnitude of the energy spread of the accelerator.

For example, in the reconstruction of B_d decays into $\pi^+\pi^-$, the signal-to-noise ratio is expected to be approximately 1:1 with a beam energy spread of 7.8×10^{-4}. It will be worsened to 1:2, if the energy spread increases by a factor of two. This is equivalent to a factor of 1.7 reduction of the luminosity.

The energy spread should, therefore, be chosen to be the smallest possible that is allowed by machine design considerations.

1.5 Beam background

As the previous sections have shown, high luminosity is required to study the CP violation and rare decays. Naturally, the KEKB machine must store an extremely high beam current. Also, a beam pipe with a small radius needs to be used at the interaction point (IP) for precise vertex measurements. Therefore, the reduction of beam background is a critical issue. It is essential to design the machine, especially the interaction region (IR), so as to reduce the beam background.

If bend magnets are used near the collision point to separate two beams, the synchrotron radiation emitted by particles passing through these magnets have to be handled with utmost care. This condition can be significantly relaxed if no separation bend magnets are used, because synchrotron radiation from other magnets will have a significantly reduced critical energy.

However, it will still be necessary to have movable masks in the straight section to absorb photons that are emitted by the beams when they go through the magnets far from the interaction point. Also, the location and size of the magnets near the IP have to be designed while taking into account the synchrotron radiation background. The aperture of beam pipe vacuum chambers needs to be allocated with sufficient margins to allow the synchrotron radiation to pass, as well as the beam during injection conditions.

The particle background due to beam-gas scattering is potentially more harmful than the synchrotron radiation in KEKB. The vacuum pressure in the IP straight section must be kept at less than 10^{-9} torr. This is required for reducing the rate of off-momentum particles directed toward the beam pipe to an acceptable level.

A set of movable masks in the arc or non-IR straight sections needs to be implemented, in order to clip the beam tail, because the long beam tail might hit the IR masks and cause severe background.

The beam background during the injection time is another important issue, considering radiation damage to the silicon vertex detector, the CsI calorimeter, and their electronics circuit. These issues have to be considered in the design of the injection scheme and the shielding of detector components.

Bibliography

[1] The BELLE Collaboration, KEK Report 94-2.

[2] "Progress Report on Physics and Detector at KEK Asymmetric B Factory", B Physics Task Force, May 1992, KEK Report 92-3.